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Economic evaluation of protein recovery process from Argentinian soybean extruded-expelled meals

Evaluación económica del proceso de recuperación de proteínas de las harinas extraídas de la soja argentina

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Abstract

Soybean extruded-expelled (EE) meals are the byproduct of the soybean oil extraction process commonly used by small and medium- sized Argentinean companies. In this study, the economic feasibility of protein concentrate production from soybean EE meals was evaluated. A processing daily capacity of 18 ton of EE meals was considered, resulting in an annual production of 1,500 ton of protein concentrate. The proposed methodology considered a pH change process consisting of 3 cycles of alkaline extraction at 60 ºC followed by isoelectric precipitation at low temperature using hydrochloric acid, which resulted in a final product with a protein content of 75 % (db) and a productivity of 0.28 kg product/kg soybean EE meals. To analyze a practical case, proposed production was carried out as an extension of a typical medium-sized soybean extrusion- expelling plant. As a result, the necessary capital investment was estimated to be US$2.7 million. Additional financial performance indicators were computed, including net present value and internal rate of return, and it was concluded that the proposal to obtain a protein concentrate from soybean EE meals was economically viable on an industrial scale if sale prices are above 2,267 US$/ton.

Keywords: agricultural production, soybean extruded-expelled meals, value-added manufacturing, protein products.

Resumen

Las harinas de extrusión-prensado de soja (EE) son el subproducto del proceso de extracción de aceite de soja utilizado habitualmente por pequeñas y medianas empresas argentinas. En este estudio se evaluó la viabilidad económica de producción de concentrados proteicos a partir de estas harinas. Se consideró una capacidad de procesamiento de 18 ton/día de harinas EE, equivalente a una producción 1.500 ton/año de concentrado proteico. La metodología propuesta consideró un proceso de cambio de pH, 3 ciclos de extracción alcalina a 60 ºC seguidos de precipitación isoeléctrica a baja temperatura utilizando HCl, resultando un producto final con contenido proteico del 75 % (bs) y una productividad de 0,28 kg de producto/kg de harinas EE. Para analizar un caso práctico, la producción propuesta se llevaría a cabo como ampliación de una planta típica de extrusión-prensado de soja de tamaño medio. Como resultado, la inversión de capital necesaria se estimó en 2,7 millones de dólares. Se calcularon otros indicadores de rendimiento financiero, como valor actual neto y tasa interna de rendimiento, y se concluyó que la propuesta de obtención de un concentrado proteico de soja era económicamente viable a escala industrial si los precios de venta son superiores a 2.267 US$/tonelada.

Palabras clave: producción agrícola, harinas de extrusión de soja, fabricación de valor añadido, productos proteicos.

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1 Introduction

Soybeans have a high protein content and are converted into different soy protein products mainly for use in the food industry. Historically, soybeans have been produced because of their high oil content, though in recent years, the interest in their nutritive value and well-balanced amino acid composition increased. During industrial soybean processing, oil is extracted by chemical (solvent extraction) or physical (expelled-pressed extraction) technologies (Johnson, 2008) and the obtained byproducts are processed as defatted (down to 0.5 % lipid content) or partially defatted (down to 7 % lipid content) meals. Soybean extruded-expelled (EE) meals are the byproduct of the soybean oil extraction process commonly used by small or medium-sized Argentinean companies and are considered partially defatted soybean meals, with an average composition of 43 % protein content and 7 % lipid content.

Argentinean soybean processing plants have adopted extrusion-expelling technology as it requires low initial capital investment, adding up to 400 small and medium-sized companies with an average soybean processing capacity of 50 ton/day, which represent approximately 10 % of the total Argentinean soybean oil production (Juan *et al*., 2015). Despite this relevant fact, limited technological development has been achieved for adding value to the supply chain of soybean EE meals (Heywood *et al*., 2001; Wang, Johnson & Wang, 2004). Currently, the by-product EE meals, commonly called expeller, are sold in the area near the processing plant as animal feedstock (Juan *et al*., 2015). However, due to the increased interest in expanding the social economy, including the growth of small and medium-sized companies and cooperatives, as well as the increasing importance of soybean protein as a food source, an optimal processing strategy for obtaining protein products from soybean EE meals has become a relevant challenge to valorize this byproduct (Ono, Soesanto & Wallenstrom, 2021). Protein products can be obtained from these meals, thus increasing its added-value and offering advantages such as providing a more concentrated source of protein according to market requirements, improving the functional properties of proteins, and reducing its undesirable properties (i.e., anti-nutritional factors) (Accoroni, 2015).

In order to contribute and support the global market of manufacturing of plant based protein ingredients, small and medium farmers need to achieve sustainable processes that add value to their primary crops. To reach this goal, the farming sector needs to efficiently adopt and implement proven agricultural innovations (Alomia-Hinojosa *et al*., 2018). It has been discussed how on-farm development supported by the federal and local governments encouraged farmers to achieve higher resilience when processing their crops (Heinemann *et al*., 2014). In particular, small and medium Argentinean farmers consider on-site industrialization of their primary production as a small contribution for attaining a sustainable economic activity (Seghezzo *et al*., 2020), so they have asked for help from the academic community for developing ways to improve their process. As a contribution, this article intends to adapt public domain technologies for processing of soybean meals and manufacturing of protein food ingredients, usually used for producing valuable soy protein products, since proteins from soybean meals present good amino acid profiles, containing tryptophan, threonine, and lysine and useful techno-functional properties (Gerlani *et al*., 2019). This new method will entail the possibility of adding value on site to expeller, a byproduct that is generally used as livestock and poultry feed, though it has potential to be economically exploited for production of protein products since it has a high content of proteins and present the advantage of being obtained without using an organic solvent.

Processing technologies for traditional soybean meals (i.e., resulting from solvent extraction) have been extensively developed for producing highly soluble protein ingredients such as concentrates (SPC), isolates (SPI) and texturized products (TSP) (Endres, 2001; Preece, Hooshyar & Zuidam, 2017). These alternatives include pH-shifting, salting-in extraction, aqueous alcohol extraction and heat processes (steam injection or jet cooking) (Endres, 2001; Johnson, 2008). In the last years, developments regarding new functionalities of soybean proteins have been reported in the literature, such as formation of soy protein microparticles for stabilizing agents of food dispersed systems (Monroy-Rodríguez *et al*., 2021) or protein hydrolysates and bioactive peptides encapsulation (Cano-Sampedro *et al*, 2021).

Soybean EE meals, compared with defatted soybean flakes obtained from processing with hexane, have a higher content of remaining oil that persists due to the lower extraction efficiency of the pressing process compared with solvent extraction (Li *et al*., 2016). However, the scale of this technology makes it easier to adapt to non-gmo productions or productions with specific requirements (Wang, Johnson & Wang, 2004). The incorporation of in situ added value processing facilities usually improves farmers' rentability, as Sanders, Altman & Ferraro (2014) evaluated the impact of soybean processing yields and the adoption of new technologies. Moreover, Le Clech & Fillat-Castejón (2017) concluded that farmer's innovation and development are the most important aspects in the formation of commodities and derivatives prices. Therefore, the economic feasibility of adding a soy protein products production plant to a typical extrusion processing plant needs to be analyzed, since it could provide valuable information for the productive development of the central rural region of Argentina (Accoroni, 2015).

The objective of this work is to evaluate the economic feasibility of producing soy protein concentrate from soybean EE meals by implementing a pH shifting method, widely applied in the literature for soy protein extraction from defatted flakes (Deak *et al*., 2008; Sunley, 1995) and adapted to EE meals, as an expansion to a typical Argentinean extruded expelling plant.

2 Materials and methods

2.1 *Process considerations*

A practical case of protein concentrate production from soybean EE meal is studied assuming that such production was carried out as an expansion of a soybean extrusion and pressing plant located in the Santa Fe province, in the Argentinean central region. The methodology considered for concentrate production is a pH-shifting process that consists of 3 alkaline extraction cycles at 60 ºC followed by isoelectric precipitation at low temperature using hydrochloric acid, as presented in Figure 1. As mentioned in the introduction section, the implemented process was based on previously developed technology (Endres, 2001; Wang, Johnson & Wang, 2004) with some modifications. In general, public domain pH shifting processes implement 1 or 2 alkaline extraction cycles. Previous to the economic evaluation of the protein extraction plant from EE here presented, an exhaustive study of the alkaline and precipitation stages was carried out at laboratory scale, where the authors demonstrated that the addition of a third alkaline extraction cycle at 60ºC recovers an extra average 12.1 ± 2.3% of the soluble proteins from the EE meals. This soybean protein concentration process from EE meals allowed obtaining a final product with a protein content upwards of 75 % and a productivity of 0.28 kg protein product/ kg expeller (Accoroni, Godoy & Reinheimer, 2020). The addition of an extra extraction cycle is justified because of the disadvantage that Argentine soybean EE meals present as the raw material, associated with their lower initial protein contents and higher residual oil content compared to hexane-defatted soy white flakes. Hence, the additional extraction cycle ensures being able to reach an adequate overall process yield for obtaining CPC from EE meals.

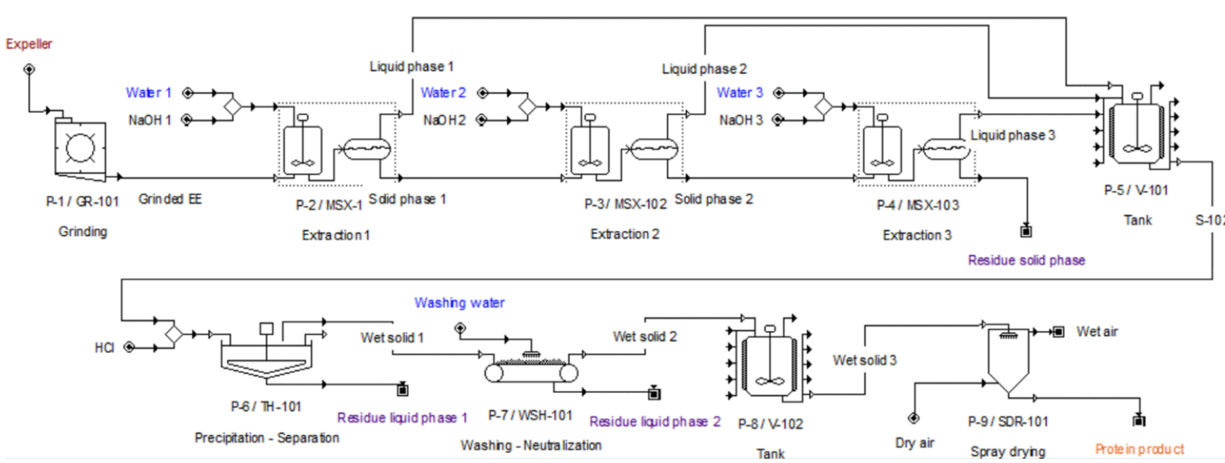

Figure 1. Soybean protein concentrate process from EE meals.

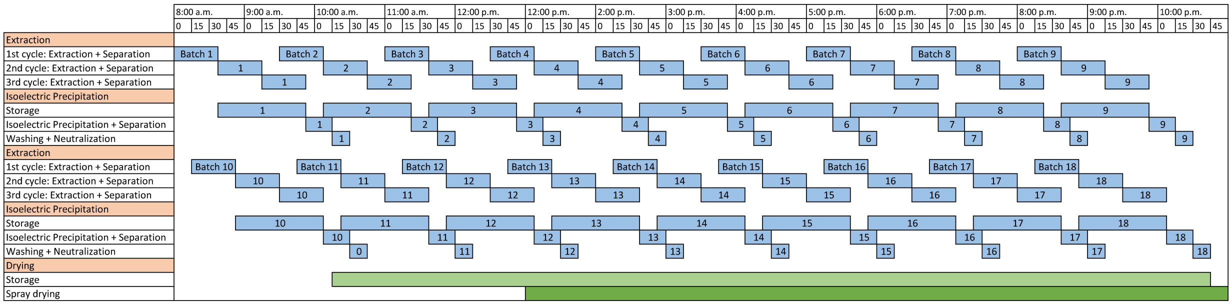

Figure 2. Gantt chart of the protein recovery process.

Table 1. Raw materials and supplies.

Item	*Unit*	*Annual quantity*	*Unit cost*	*Annual cost*
Expeller	ton	5400	\$178.50	\$963,900
Sodium hydroxide	m^3	240	\$250.00	\$60,000
Hydrochloric acid	m^3	400	\$240.00	\$96,000
Raw materials and supplies				\$1,119,900

2.1.1 Production plant considerations

It is assumed that the installed capacity for soybean processing is 50 ton/day, and that the plant operates 17 hours daily for 6 days a week. These conditions add up to 5,100 productive hours per year. Regarding the location of the new production plant for the protein concentrate from EE meal, it is proposed to be constructed as an extension of the existing extruding-expelling oil extraction plant and, therefore, located on the same property while using the existing land, facilities and necessary basic services.

2.1.2 Batch production conditions

For the concentrate production from soybean EE meals, a batch strategy is adopted. Each batch consists of 3 successive extraction cycles of 15 min, followed by centrifugation for separating the solid fraction from the protein extracts. After this extract separation, the isoelectric precipitation and subsequent protein product recovery is carried out. The protein product obtained is washed with water in a 1:1 ratio and then neutralized with 1N NaOH solution until reaching a pH value of 7.

In Figure 2, the Gantt chart shows all the proposed production stages during a daily production cycle. It consists of a first half hour for starting up, a last half hour for equipment cleaning (both not included in the diagram), and the remaining 16 hours to carry out 18 successive batches of extraction, isoelectric precipitation, washing and neutralization. Finally, as the product drying step operates continuously, the washed and neutralized protein product is stored in an intermediate tank until spray drying begins after batch 8 and is carried out throughout the last 9 hours of the day.

2.2 Investment project

2.2.1 Fixed and variable costs

The estimation of fixed and variable costs includes equipment, installation, utilities, raw materials and supplies, and salaries. The following data sources were considered: updated reference quotations from both national and foreign companies for equipment; methodology proposed by Mustakas & Sohns (1976) for estimation of installation costs; local prices for utilities, including electricity, gas and drinking water; and the collective wages agreement for feed mills workers. The process equipment includes a grinding and screening line, two parallel lines of three extraction cycles each, and a spray drying line that operates continuously.

Raw material and supplies costs are described in Table 1. The total equipment acquisition cost is calculated based on quotes from equipment suppliers, as well as from catalogs available in the market, as detailed in Table 2. Table 3 shows the current industrial tariffs for utilities.

Table 2. Equipment acquisition.

Item	*Unit*	*Quantity*	*Unit cost*	*Annual cost*
Mill	unit	1	$50,000	$50,000
Sieve	unit	1	$10,000	$10,000
Agitated tank	unit	8	$34,600	$276,800
Decanter centrifuge	unit	7	$21,400	$149,800
Mixing transfer pump	unit	8	$7,700	$61,600
Boiler	unit	1	$70,000	$70,000
Spray dryer	unit	1	$541,667	$541,667
Cleaning equipment	unit	1	$36,667	$36,667
Subtotal				$1,196,534
Auxiliary Equipment			5%	$59,827
Total Equipment Cost				$1,256,360
Installed Equipment Cost			43%	$1,796,595

Table 3. Utilities.

Item	*Unit*	*Annual quantity*	*Unit cost*	*Annual cost*
Electricity - Industrial Use Tariff	kW	1,738,700	$0.05	$92,471
Water - Industrial Use Tariff	m^3	270,000	$0.15	$40,170
Gas - Industrial Use Tariff	m^3	2,835,903	$0.10	$272,432
Utilities				$405,072

Table 4. Salaries.

Item	*Unit*	*Annual expenditures*	*Gross monthly salary*	*Annual salary*
Professionals and Supervisors	unit	26	$1,000	$26,000
Workers	unit	52	$500	$26,000
Salaries				$52,000

Table 5. Capital investment.

Item	*Factor*	*Annual cost*
Equipment acquisition costs		$1,796,595
Piping, Lines and Connections	10%	$179,660
Civil Constructions	15%	$269,489
Contingencies	10%	$179,660
Fixed Capital		$2,425,404
Working Capital	10%	$242,540
Capital Investment		$2,667,944

Finally, salaries are presented in Table 4, including: 4 operators, a plant manager, and a general manager.

2.2.2 *Capital investment*

The necessary capital investment consists of fixed capital, working capital and initial start-up costs, as shown in Table 5. Fixed capital is composed of equipment acquisition costs, as well as installation connections, civil construction and contingencies costs, which are estimated as a percentage of the former one. The working capital is considered as 10 % of the fixed capital.

2.2.3 Total annual cost

To calculate the total annual cost, a facility's useful life of 25 years and a 35 % discount rate are adopted. In addition, a protein product sale price range of 2,000 to 3,000 US$/ton is considered. The reference prices are the values of Argentinean imports made in 2019, resulting in an average value of 2,410 US$/ton and a range of 2,260 - 2,700 US$/ton (Comtrade, 2021). It is also considered that the remaining by-product of the extractions will be sold as animal feed at a value of 125 US$/ton.

3 Results and discussion

3.1 Productivity

The estimated productivity of the proposed soybean concentrate process was 0.28, which means that for every kg of EE meal processed is obtained 0.28 kg of final product. Furthermore, 75 % of the produced EE meals is destined to the production of concentrate, while the remaining 25 % continues to be sold as animal feedstock. Therefore, based on the installed capacity, it resulted in a production of 5 ton/day of protein concentrate, or equivalently, 1,500 ton/year. Table 6 summarizes the soybean concentrate productivity based on soybean feedstock, EE meals and water consumption.

Comparing the obtained productivity values and bibliographic data referred to protein concentrates and isolates production (Sunley, 1995), it is evident the values resulting from EE meals are lower than those reported for defatted non toasted soybean meal processing. Campbell *et al*. (1981) postulated that the soybean protein concentrates productivity obtained by alcohol leaching reaches 0.75 kg of protein concentrate per kg of toasted defatted soybean meal, starting from a material with 45 % (db) of protein and obtaining a concentrate with 60 % (db) of protein; while regarding soy protein isolate productivity, it is approximately 0.3 kg of product per kg of non-toasted defatted soybean meal, with a protein recovery yield of about 75 % (Kolar *et al*., 1985). In conclusion, it is evident that both productivity and protein recovery yield decrease when replacing non-toasted defatted soybean meal with EE meals.

3.2 Byproducts and effluents

Process by-products are the solid fibrous residue and liquid effluent. On one hand, solid residue can be commercialized in wet or dried form as animal feedstock. On the other hand, liquid effluent volumes, which are obtained after protein separation, can be purified by reverse osmosis or nanofiltration. Thus, the potential disadvantage of the high water consumption of the proposed process could be solved by concentrating solutes and reusing recovered water as solvent in a new batch. This by-product valorization proposal would improve the process both from an economic and environmental point of view, rendering it more sustainable.

3.3 Economic feasibility of the process for protein recovery from soybean expeller

For the economic feasibility analysis, the following were considered: 26,600 kg of EE (75 % of 35,000 ton/day), 17 productive hours, reference sales price of 2,419 US$/ton and a concentrate production of 5 ton/day. Table 7 presents the cash flow analysis for five scenarios given by different product sales prices.

From the financial indicators shown in Figures 3, 4 and 5, it is evident that the net present value, the internal rate of return and the payback period increase at higher product prices. It can also be seen that the break-even point corresponds to a product selling price of 2,267 US$/ton. This value is lower than the average reference price of 2,410 US$/ton obtained from imports made by Argentina in 2019 (Comtrade, 2021).

Table 6. Soybean protein concentrate productivity.

Productivity	*kg product / kg initial*
Soybean concentrate productivity per ton of soybean feedstock	0.224
Soybean concentrate productivity per ton of EE meals	0.28
Soybean concentrate productivity per ton of used water	0.005

Table 7. Cash flow analysis for five scenarios given by different product sales prices.

	Factor	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*
Sale Price (ton)		$2,000.00	$2,250.00	$2,500.00	$2,750.00	$3,000.00
Product Sales		$3,024,000	$3,402,000	$3,780,000	$4,158,000	$4,536,000
By-product Sales		$486,000	$486,000	$486,000	$486,000	$486,000
Revenue		$3,510,000	$3,888,000	$4,266,000	$4,644,000	$5,022,000
Raw Materials and Supplies		($1,119,900)	($1,119,900)	($1,119,900)	($1,119,900)	($1,119,900)
Salaries		($52,000)	($52,000)	($52,000)	($52,000)	($52,000)
Utilities		($405,072)	($405,072)	($405,072)	($405,072)	($405,072)
Environmental Impact Mitigation	25%	($279,975)	($279,975)	($279,975)	($279,975)	($279,975)
Maintenance	15%	($167,985)	($167,985)	($167,985)	($167,985)	($167,985)
Marketing	25%	($279,975)	($279,975)	($279,975)	($279,975)	($279,975)
Gross Income Tax	1,5 %	($52,650)	($58,320)	($63,990)	($69,660)	($75,330)
Depreciation	20%	($485,081)	($485,081)	($485,081)	($485,081)	($485,081)
Total Cost		($2,842,638)	($2,848,308)	($2,853,978)	($2,859,648)	($2,865,318)
Profit Before Taxes		$667,362	$1,039,692	$1,412,022	$1,784,352	$2,156,682
Income Tax	35%	($233,577)	($363,892)	($494,208)	($624,523)	($754,839)
Profit After Taxes		$433,785	$675,800	$917,814	$1,159,829	$1,401,843
Capital Investment		$2,667,944	$2,667,944	$2,667,944	$2,667,944	$2,667,944

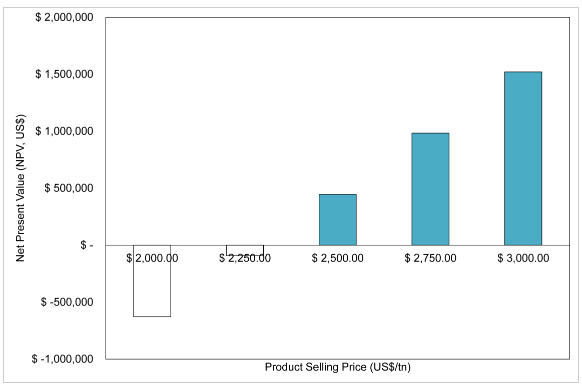

Figure 3. Net present value.

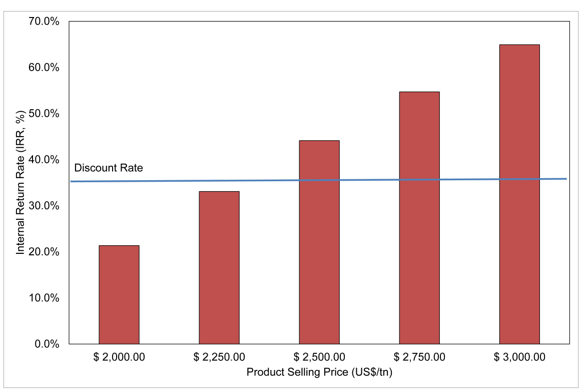

Figure 4. Internal rate of return.

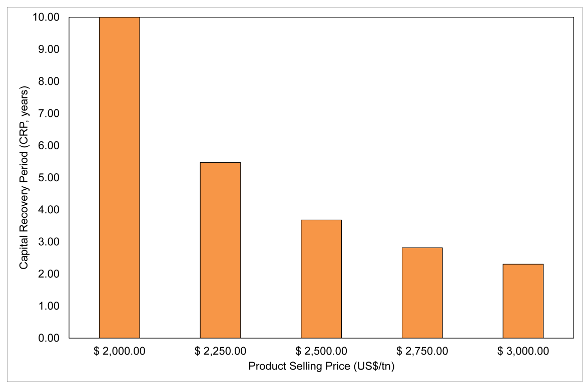

Figure 5. Capital recovery period.

It is concluded that for scenarios 1 and 2 the project is not feasible given that the net present value is positioned below the break-even point. In addition, the internal rate of return is lower than the adopted reference rate (35.0 %) and more than 5 years are required to recover the capital investment. On the other hand, from scenario 3 onwards, the outlook is favorable when considering a sales price equal to or higher than 2,500 US$/ton. The last scenario is the most favorable, with a positive NPV, an IRR higher than the 35.0 % benchmark and a capital recovery period of 2 years and 4 months.

Conclusions

The economic feasibility analysis is carried out for a production plant for soybean concentrate from EE meals, as an expansion of a soybean oil extrusion and pressing plant. There, 75 % of the by-product EE meals are destined to the production of concentrate, while the remaining 25 % continues to be sold as animal feedstock. In this study, it was considered that the installed capacity for protein concentrate processing is 5 ton/day, resulting in an annual production of 1,500 ton/year. For this, the required capital investment is US$ 2.7 million.

Regarding the financial analysis of this proposal, different financial indicators are estimated, including the net present value, internal rate of return and payback period. The average soybean concentrates price of Argentinean imports in 2019 was 2,410 US$/ton. When comparing with the volumes typically processed by small and medium-sized companies in the region, it is here concluded that the proposal to obtain a protein concentrate from soybean EE meals is economically viable on an industrial scale if the sale price of the concentrate is higher than 2,267 US$/ton, given that the internal rate of return for that value turns out to be higher than the discount rate and the payback period is less than 5 years. Thus, the proposed project is economically feasible if the prices of imported concentrate remain at least at historical average values.

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